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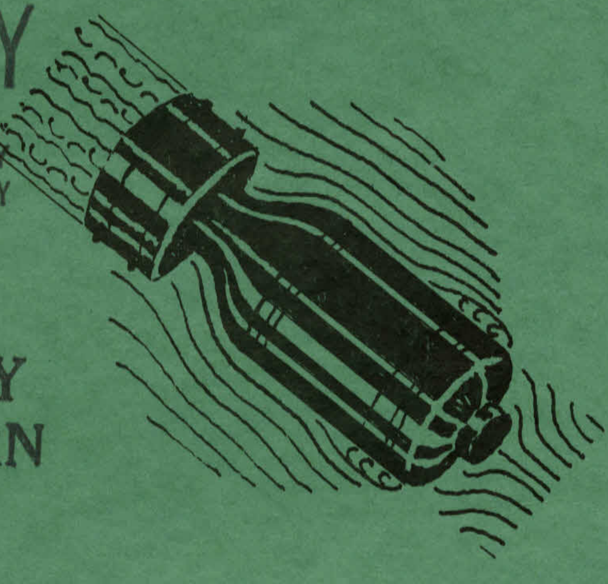
WATER TUNNEL TESTS
OF THE
HYDROBOMB.



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA.

SECTION No 6.1 · Sr - 207-1276.

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WATER TUNNEL TESTS

OF THE

HYDROBOMB

BY

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THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRAULIC MACHINERY LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1 sr-207-1276

HML Rep. No. ND-29

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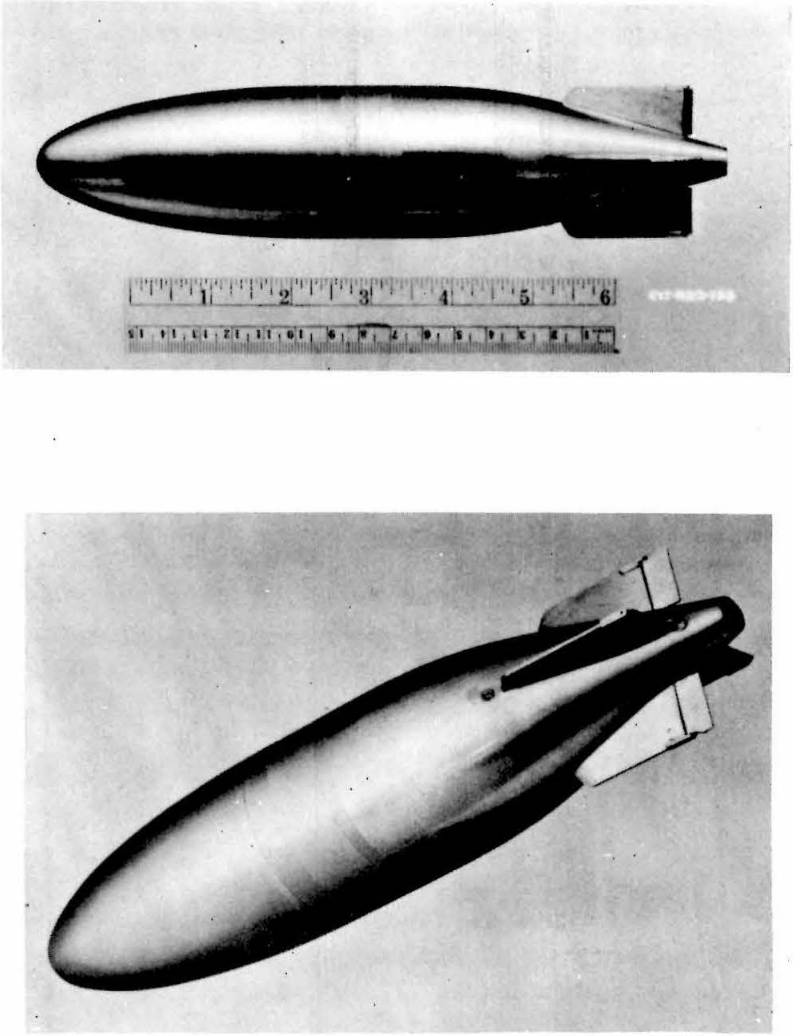
May 13, 1944



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PHOTOGRAPHS OF 2 INCH DIAMETER MODEL

FIGURE 1

WATER TUNNEL TESTS
OF THE
HYDROBOMB

GENERAL

This report covers Water Tunnel tests of a 2" diameter model of the hydrobomb, conducted at the Hydraulic Machinery Laboratory at the California Institute of Technology. This work was authorized by Dr. E. H. Colpitts, Chief of Section 6.1, NDRC, as a part of Project OD-99. The purpose of the tests was to determine the drag, cross force, moment, and center-of-pressure eccentricity for various settings of the vertical and horizontal rudders, and also the extent to which these rudders are effective in controlling the torpedo. Runs were also made to determine the cavitation effects produced under the specified operating conditions, namely, a velocity of 70 miles per hour and a submergence of 15 feet. Photographs were taken showing a wide range of cavitation effects.

The report includes curves giving the performance characteristics as well as flow line drawings made by observing the model in the Polarized Light Flume.

Appendix A gives definitions of the terms used in this report as well as a brief discussion of the required conditions for stability in a projectile.

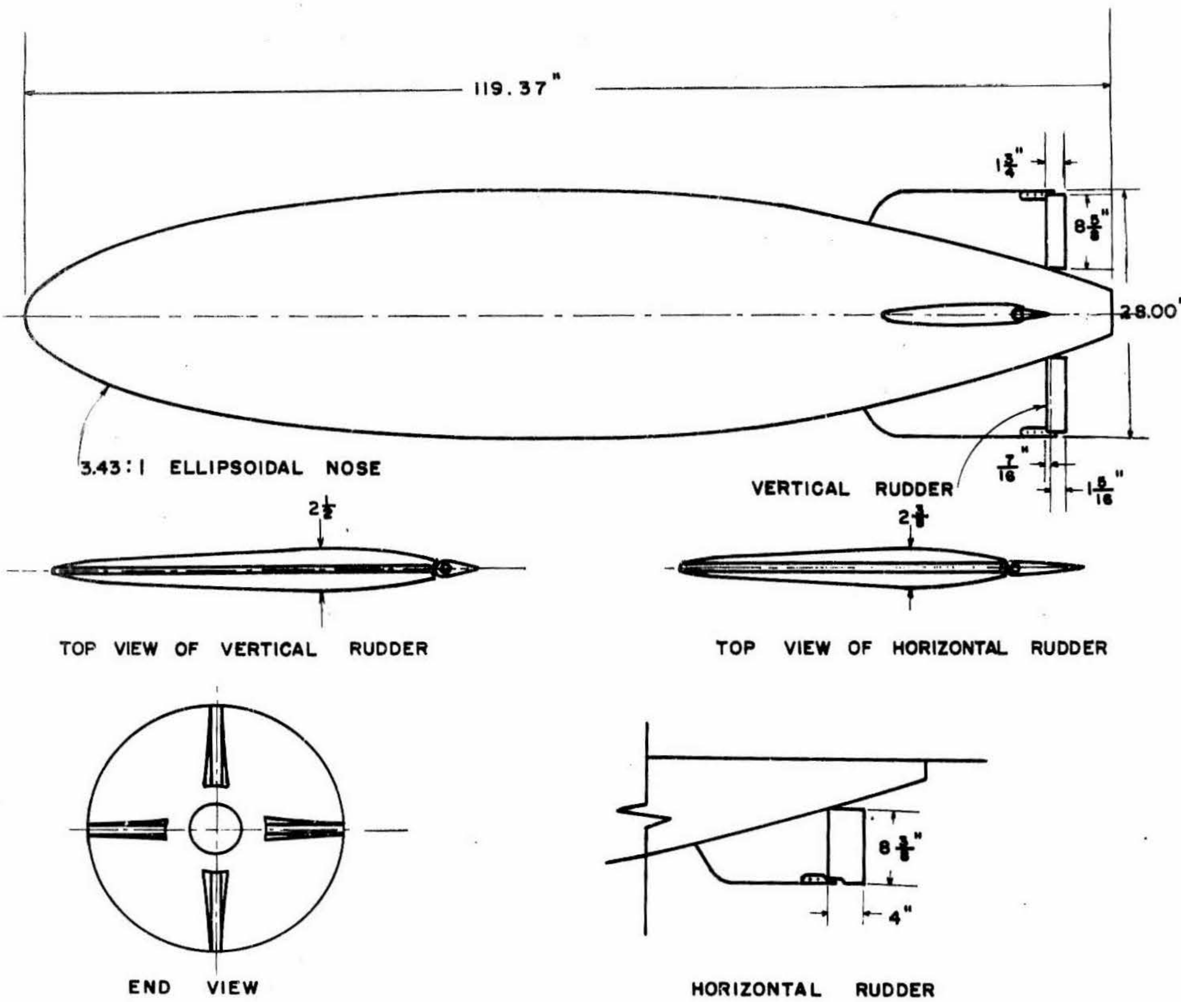
DESCRIPTION OF PROJECTILE

The hydrobomb has a long, ellipsoidal nose and an abruptly tapering afterbody. It is equipped with both vertical and horizontal rudders located aft of rather thick fins, the vertical rudders being approximately one-third as wide as the horizontal rudders.

Physical Data

Diameter	28 inches
Length over all	119.37 inches
C.G. distance from nose	57.44 inches
Nose design	3.43:1 Ellipsoid

Figure 1 shows two views of the 2" diameter model made for the tests and Figure 2 shows an outline drawing of the prototype.



OUTLINE DRAWING
OF PROTOTYPE

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FIGURE 2

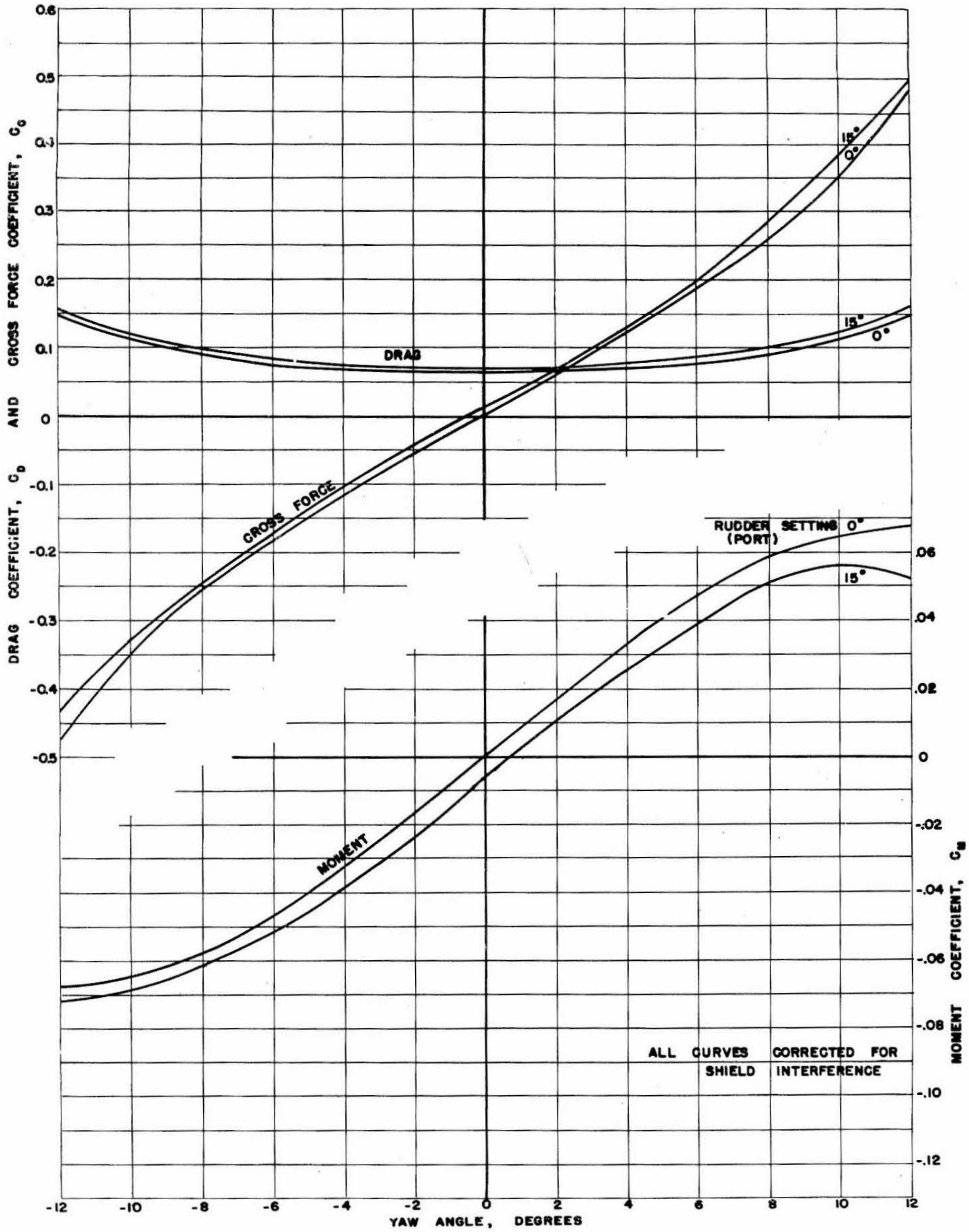
PERFORMANCE CHARACTERISTICS

In Figure 3 are shown performance curves for neutral horizontal rudders and 0° and 15° port settings for the vertical rudders. These curves give the variation in drag, cross force, and moment with varying angles of yaw. All of these curves have been corrected for the interference of the supporting structure.

From the curves in Figure 3 it is seen that, with both vertical and horizontal rudders in the neutral position, the drag coefficient varies from 0.065 at zero yaw to 0.15 at 12° yaw; the cross force coefficient varies from zero at 0° yaw to 0.48 at 12° yaw; the moment coefficient varies from zero at 0° yaw to 0.068 at 12° yaw. With the vertical rudders set at 15° port very little change in the drag and cross force is noted, the principal change being in the moment. The drag coefficients in Figures 3 and 4 were determined from tests with a tunnel velocity of 32 feet per second and are believed to be lower than will be obtained with the prototype for the reasons given under "VELOCITY AND DRAG". The 15° port setting for the vertical rudders changes the moment coefficient at -12° yaw from -0.068 to -0.072, at 0° yaw the moment coefficient is changed from zero to -0.006 and at +12° yaw it is reduced from +0.068 to +0.052. The curve shows that there is a slight stabilizing moment, with 15° port rudder setting, extending from 0° to +3/4° yaw angle. In other words, this represents the small angle of yaw for which the projectile is under control of the vertical rudder.

Figure 4 shows the performance curves for neutral vertical rudders and the horizontal rudders set at 0°, 5°, 10°, and 15° *down*. As the horizontal rudders have about three times the area of the vertical rudders, this easily accounts for the relatively greater effect which they produce in the drag, lift, and moment. An examination of the moment coefficient curve shows that 5°, 10°, and 15° *down* settings of the horizontal rudders produce a stabilizing moment for positive pitch angles from 0° to 1-3/4°, 0° to 3-1/2°, and 0° to 6-1/2°, respectively. For all other pitch angles the moment is destabilizing. This means that a maximum setting of 15° for the horizontal rudders will control the projectile for pitch angles within a range of 0° to ± 6-1/2°.

Figures 5 and 6 reproduce flow line drawings made from careful observations of the model in the Polarized Light Flume. Figure 5 shows all rudders neutral with 0° and 10° pitch and Figure 6 shows the horizontal rudders set at 10° down with 0° and 10° pitch. The drawings clearly show that there is very little disturbance of the flow about this well streamlined body. As would be expected, the horizontal rudder fin at 10° pitch causes some disturbance and there is a small amount due to the square end of the afterbody.

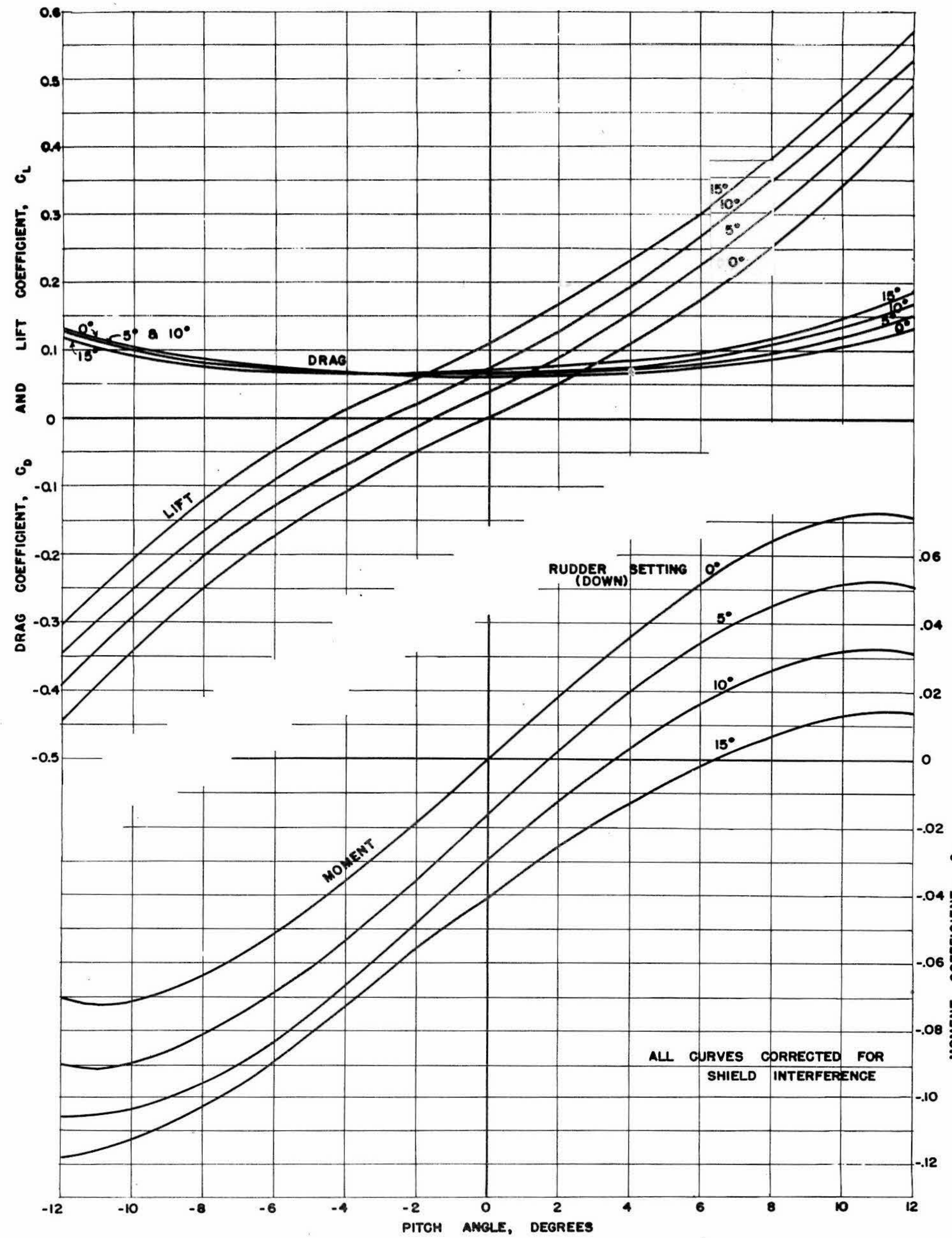


DRAG, CROSS FORCE, AND MOMENT COEFFICIENTS

HORIZONTAL RUDDERS 0°

VERTICAL RUDDERS 0°, 15°

FIGURE 3



<u>DRAG, LIFT, AND MOMENT COEFFICIENTS</u>
VERTICAL RUDDERS 0°
HORIZONTAL RUDDERS 0°- 5°- 10°-15°

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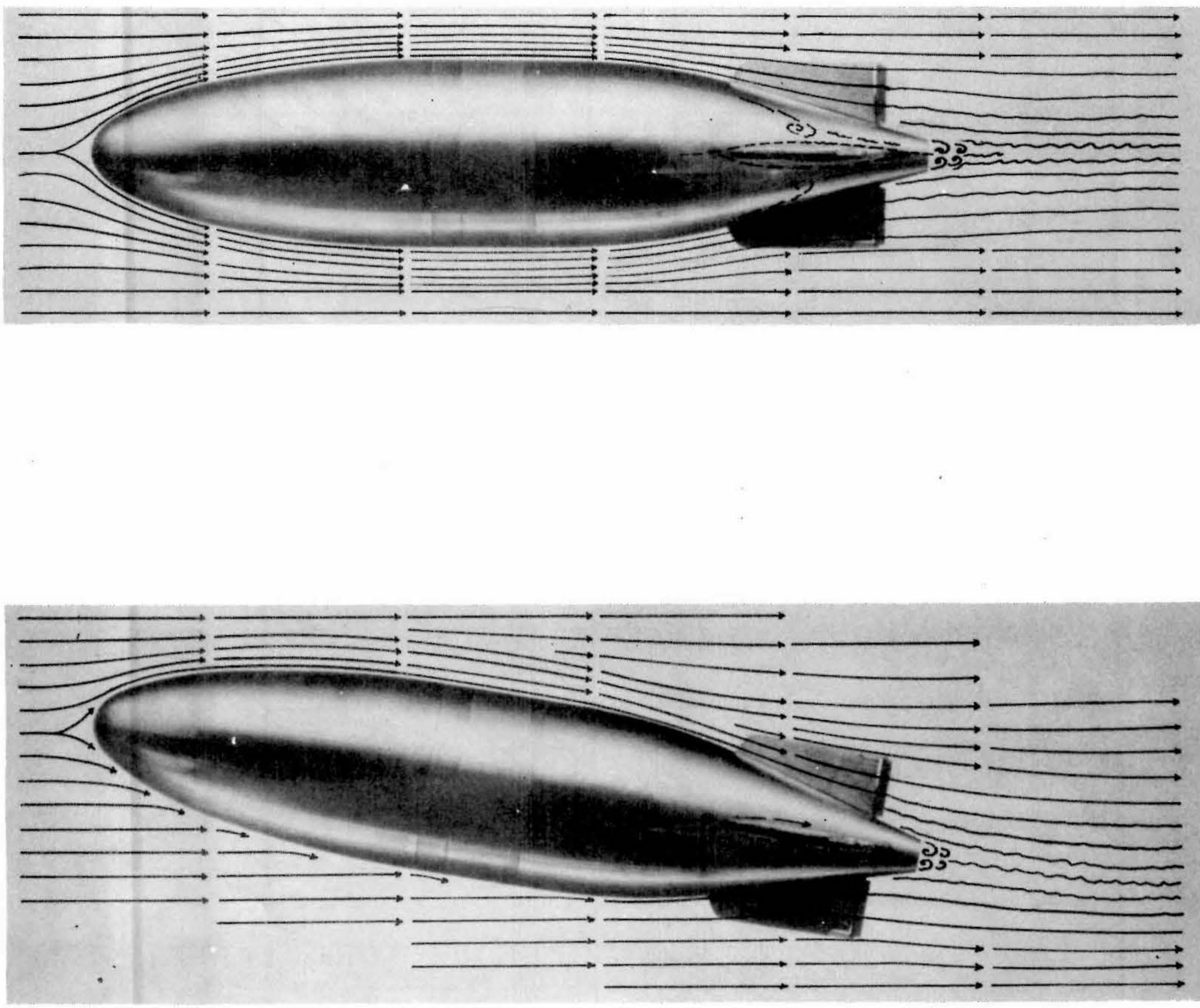
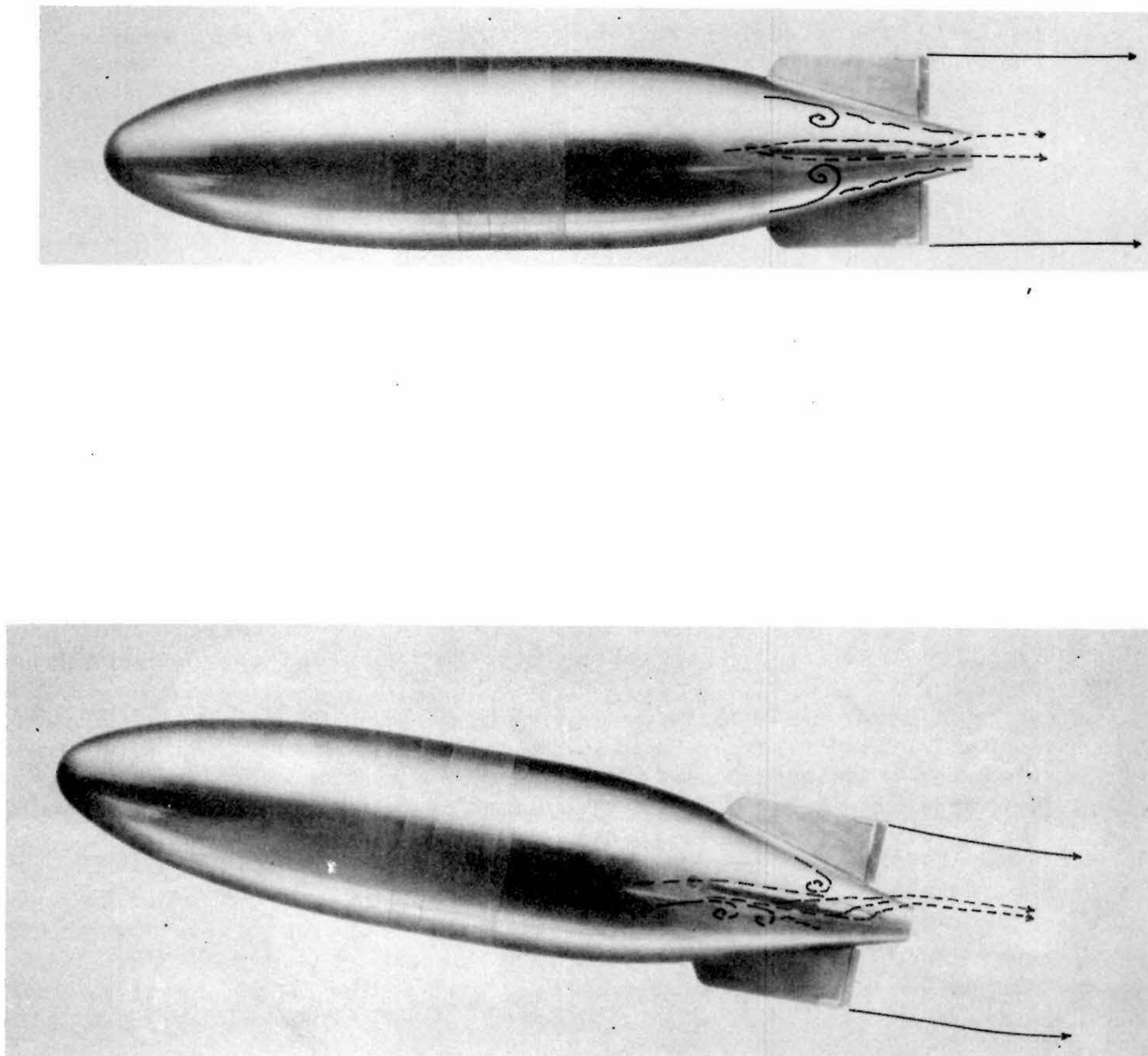
FIGURE 4



FLOW LINE DRAWINGS
AT 0° AND 10° PITCH
ALL RUDDERS NEUTRAL

FIGURE 5



FLOW LINE DRAWINGS

AT 0° AND 10° PITCH

HORIZONTAL RUDDERS 10° DOWN

VERTICAL RUDDERS NEUTRAL

FIGURE 6

VELOCITY AND DRAG

Figure 7 shows the results of tests made to determine the variation in drag with change in Reynolds number. In these tests the drag coefficients were obtained for water velocities in the tunnel varying from 10 to 60 ft per sec. The Reynolds number, R, is calculated as follows:

$$R = \frac{V\ L}{\nu}$$

in which

V = velocity of projectile in feet per second

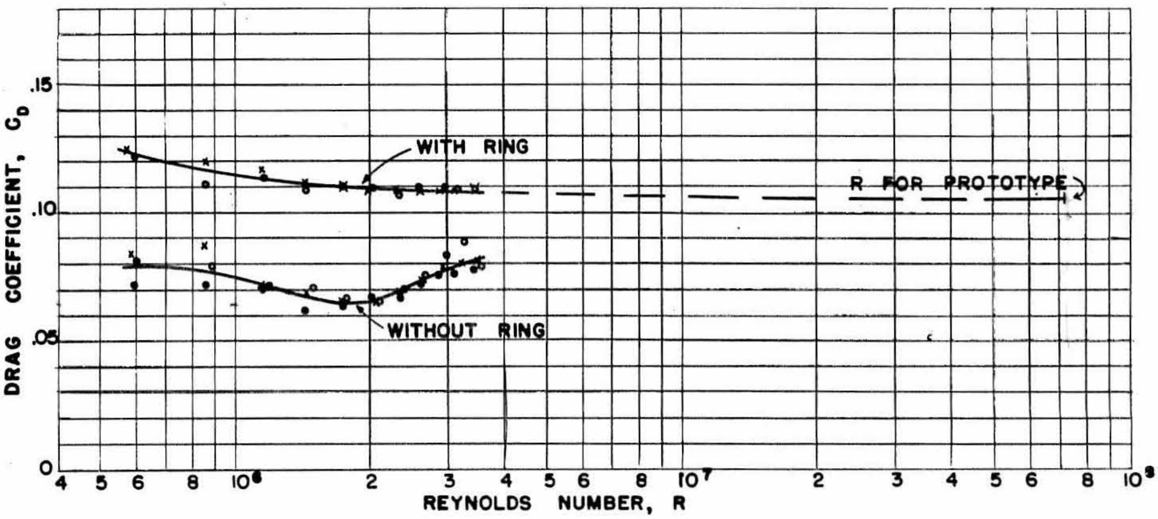
L = length of projectile in feet

ν = kinematic viscosity of the fluid in sq ft per sec

The lower curve has been drawn through the observed points obtained from tests on the model. The shape of this curve is attributed to a laminar boundary layer resulting from this highly streamlined body. As the prototype will travel at velocities nearly twice as great as the maximum under which the model could be tested and as the length scale is 1:14, it is certain that the boundary layer in the prototype will be turbulent and not laminar.

In order to observe the performance of the model with a turbulent boundary layer, a 1.86" diameter "spoiler" ring of 0.018" diameter wire was cemented to the nose of the model and the relation between drag coefficient and Reynolds number determined. The results of these tests are shown in the upper curve of Figure 7. This curve shows a higher drag, which is no doubt due in part to the increased resistance caused by the wire but also to the greater skin friction resulting from the turbulent flow. It would seem proper to assume that the true value of the drag for the prototype would lie somewhere between the values given by these two curves.

The Reynolds number for the prototype under operating conditions is 7×10^7 and by extrapolating graphically the drag-Reynolds number curve to this value, we find the drag coefficient to be in the neighborhood of 0.10. This is as close an approximation to the true value as the experimental data will justify and is believed to be high for this type of projectile, being attributable to the blunt afterbody.



RELATION BETWEEN DRAG AND REYNOLDS NUMBER

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FIGURE 7

CAVITATION TESTS

A series of runs was made to determine the effects of cavitation for several values of the cavitation parameter, K. These runs consisted of operating at a constant water velocity of 60 feet per second with a wide range of water pressures. The point of incipient cavitation was carefully noted and, in addition, observations were made at several advanced stages of cavitation. Photographs were taken of the model showing cavitation at several values of K. These appear as Figures 8 to 11.

In Figure 8 there can be seen a slight cavitation effect at the junction of the support shield with the afterbody, and for this condition the value of the cavitation parameter, K, is 0.63. In Figure 9, for K = 0.27, there is seen some cavitation on the afterbody and the forward flank of the fin. In Figure 10 cavitation is seen to be well developed over the greater part of the afterbody. Figure 11, which is about the same as Figure 10, was taken at the value of K for incipient cavitation on the nose. In fact, nose cavitation can be seen in both Figures 10 and 11 at the junction between the ellipsoidal nose profile and the cylindrical body. This is the usual location at which cavitation starts on such shapes. Cavitation in the incipient stage can usually be detected only by careful observation of the model but will rarely show in a photograph.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, what is called the cavitation parameter has been found to be very useful. This is defined as follows:

$$K = \frac{P_L - P_V}{\rho \frac{V^2}{2}}$$

in which

K = cavitation parameter

P_L = absolute pressure of the fluid in lbs/sq ft

P_V = vapor pressure of the fluid in lbs/sq ft corresponding to fluid temperature

ρ = mass density of the fluid in slugs per cu ft or $\frac{w}{g}$

w = weight of fluid in lbs per cu ft

g = acceleration of gravity

V = velocity of the projectile in ft per sec

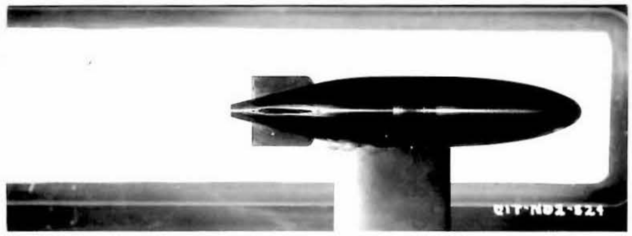


FIGURE 8

K = 0.63

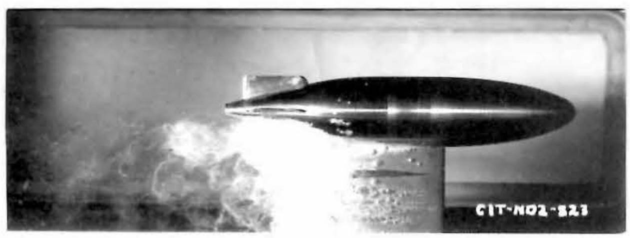


FIGURE 9

K = 0.27

(CAVITATION ON FORWARD FLANK OF FIN)

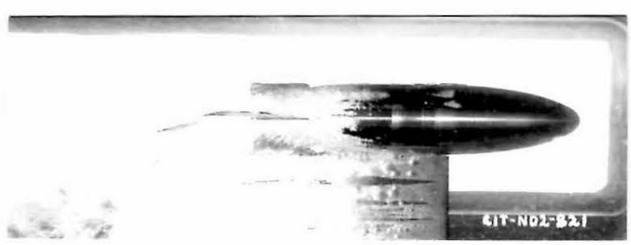


FIGURE 10

K = 0.21

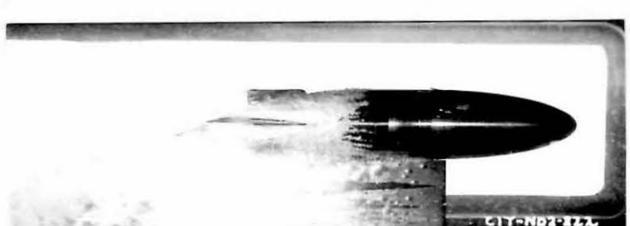


FIGURE 11

K = 0.20

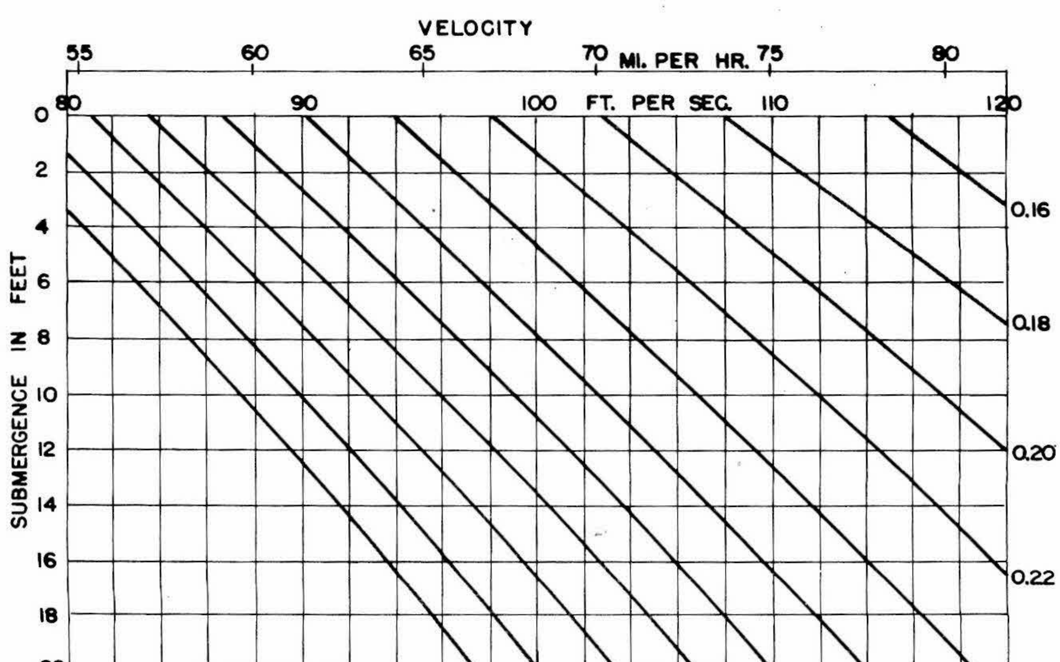
(INCIPIENT CAVITATION ON NOSE)

PHOTOGRAPHS OF HYDROBOMB MODEL
SHOWING CAVITATION EFFECTS FOR VARIOUS VALUES OF K
(3.43 : 1 ELLIPSOIDAL NOSE).

CAVITATION AND SUBMERGENCE

It is understood that this projectile is designed to operate at a velocity of 70 miles per hour (102.5 ft per sec) with a submergence of 15 feet. Using the formula in the foregoing paragraph and assuming operation in sea water at 50° F temperature, the corresponding value for the cavitation parameter is found to be 0.29. This value can also be read from Figure 12, which gives values of K for various values of velocity and submergence. An examination of Figure 9, which shows the cavitation effect for a value of K = 0.27, indicates that the bomb will be practically free from cavitation under the specified conditions of velocity and submergence.

The significance of Figure 10 is that the nose has a much better cavitation resistance than is necessary to meet the operating conditions. Although this is quite acceptable from the hydrodynamic aspect, it is accompanied by two disadvantages from the standpoint of the practical application. The high cavitation resistance is obtained by making the nose long and pointed. This is uneconomical of explosive space and tends to increase the ratio of length to diameter of the charge, which may decrease the effectiveness of the explosion. Also, experience has shown that the more pointed the nose, the greater the difficulty of obtaining satisfactory water entry in high speed airplane launchings.



RELATION BETWEEN VELOCITY, SUBMERGENCE AND CAVITATION PARAMETER, K

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FIGURE 12

CONCLUSIONS

Several important conclusions can be drawn from the results of these tests:

a. The ellipsoidal nose is more highly streamlined and has a much lower cavitation parameter than is required for the specified operating conditions. A more blunt nose would have the advantage of the center of gravity of the charge being further forward and would also provide better entry conditions. Tests on a number of spherogive noses indicate that a 3 caliber ogive with a 0.4 caliber spherical tip should be highly satisfactory for this bomb. This spherogive nose would have a cavitation parameter, K, of 0.3 and is so proportioned that the initial cavitation would occur on the sphere, thus giving the best condition for entry.

b. The afterbody tapers too abruptly and should be redesigned to give a better streamlined shape. A better afterbody would reduce the drag and increase the cavitation resistance.

c. The tests show that very little control is obtained from the vertical rudders. This is partly due to their small size and partly to the great thickness of the fins. It would appear to be very desirable to make the fins thinner and reverse them by having the greatest thickness forward instead of aft, this being the required shape for well streamlined bodies.

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY

APPENDIX A

DEFINITIONS

YAW ANGLE

The angle which the axis of the model makes with the direction of flow. Looking down on the model, yaw angles in a counter-clockwise direction are negative (-) and in a clockwise direction, positive (+)

MOMENTS

Moments tending to rotate the model in a counter-clockwise direction (when looking down on the model) are negative (-), and those causing clockwise rotation, positive (+).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle.

In all model tests the moment is measured about the point of support.

Moments about the center of gravity have the symbol, M_{cg}.

DRAG

The force, in pounds, exerted on the model parallel with the direction of flow.

CROSS FORCE

The force, in pounds, exerted on the model normal to the direction of flow. A positive cross force is defined as one acting in the same direction as the displacement of the projectile nose for a positive yaw.

NORMAL COMPONENT

The sum of the components of the drag and cross force acting normal to the axis of the model. The value of the normal component is given by the following:

$$N = (D \sin \psi + C \cos \psi)$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

ψ = Yaw angle in degrees

CENTER OF PRESSURE

The point in the axis of the model at which the resultant of all forces acting on the model is applied. This has the symbol (CP).

CENTER-OF-PRESSURE ECCENTRICITY

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (L) of the model. The center-of-pressure eccentricity (e) is derived as follows:

$$e = \frac{(L_{cp} - L_{cg})}{L} = \frac{1}{L} \quad \frac{M_{cg}}{N}$$

in which

e = Center-of-pressure eccentricity

L = Length of model in feet

L_{cg} = Distance from nose of projectile to CG in feet

L_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The three force coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D}$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D}$$

Moment Coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D L}$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

ρ = Density of the fluid in slugs/cu ft

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D = Area in sq ft of a cross section at the cylindrical portion of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = moment in foot-lbs measured about any particular point on the geometric axis of the projectile

L = overall length of the projectile in feet

GENERAL DISCUSSION

The curves of force and moment coefficients and of center-of-pressure distance plotted as functions of the yaw angle are useful for a discussion of the stability of projectiles. Since these tunnel tests are made under steady flow conditions, the results will only indicate the tendency of the projectile to return to or move away from the equilibrium position after a disturbance. Adopting aerodynamic usage, a projectile is said to be "statically" stable if it tends to return to equilibrium when disturbed. In the discussion of static stability the actual motion following the perturbation is not considered at all. In fact, a projectile may oscillate about the equilibrium position without ever remaining in it. In this case the projectile would be statically stable even though "dynamically" unstable. For a complete discussion of the mode of motion to be expected following a perturbation, the "dynamic" stability, additional information is necessary.

The condition for equilibrium is satisfied if C_M, calculated about the CG is equal to zero. In general, for projectiles with axial symmetry the moment is zero at $\psi = 0^{\circ}$, so that for equilibrium the projectile is oriented with its axis parallel to the direction of motion. If the projectile is rotated from the equilibrium position so as to give it a positive yaw angle, it is necessary that it have a negative moment coefficient, according to the sign convention adopted, in order that it be statically stable. Thus, a negative slope of the curve, C_M, vs. ψ corresponds to static stability, and a positive slope corresponds to instability. The degree of stability or instability is indicated by the magnitude of the slope. The same conclusions are obtained by interpreting the center-of-pressure curves. For symmetrical projectiles, if the center of pressure falls behind the center of gravity, a restoring moment exists and the projectile is statically stable. If the CP lies ahead of the CG, the moment is non-restoring and the projectile is statically unstable. The degree of stability or instability is indicated by the distance between the center of gravity and center of pressure.